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(54) **MOTION COMPENSATION IN ENERGY-SENSITIVE COMPUTED TOMOGRAPHY**

BEWEGUNGSAUSGLEICH IN EINER ENERGIEEMPFINDLICHEN COMPUTERTOMOGRAFIE

COMPENSATION DE MOUVEMENT DANS UN SYSTÈME DE TOMODENSITOMÉTRIE SENSIBLE À L'ÉNERGIE

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- **ERIK H W MEIJERING * ET AL: "Retrospective Motion Correction in Digital Subtraction Angiography: A Review" IEEE TRANSACTIONS ON MEDICAL IMAGING, IEEE SERVICE CENTER, PISCATAWAY, NJ, US, vol. 18, no. 1, January 1999 (1999-01), XP011035821 ISSN: 0278-0062**

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Description

[0001] The present application relates to motion compensation in computed tomography (CT). While it finds particular application to cardiac imaging in medicine, it also relates to other medical and non-medical applications in which it is desirable to compensate for motion in an object under examination.

[0002] CT scanners have proven to be invaluable in medical and other applications in which it is necessary to obtain information about the internal structure or function of an object. In medical imaging, for example, CT scanners are widely used to provide images of and other information regarding the physiology of human patients. A relatively recent trend has been the adoption of multi-slice CT, as increasing the axial coverage of a CT scanner can have a number of advantages, including an improved ability to scan moving portions of the anatomy, shorter scan times, and improved scanner throughput.

[0003] One important application of computed tomography is cardiac imaging. Although the increased axial coverage of multi-slice scanners, the use of relatively faster gantry rotation speeds, and other advances have improved the temporal resolution of practical CT systems, the motion of the beating heart can lead to blurring and other artifacts in the reconstructed image data.

[0004] One technique for reducing the impact of cardiac and other motion has been the use of gating techniques. In prospective cardiac gating, for example, the scan is conducted so that projection data is acquired at the desired phase or phases of the cardiac cycle. In retrospective cardiac gating, projection data acquired during the course of a scan is selected or gated for reconstruction based on the cardiac phase at which it was acquired. The projection data is selected so as to obtain projection data collected over an angular range which provides a complete CT data set. *See, e.g.,* Woodhouse et al., Coronary Arteries: Retrospective Cardiac Gating Technique to Reduce Cardiac Motion Artifact in Spiral CT; Radiology 1997:566-569.

[0005] The article "3D tomographic reconstruction of coronary arteries using a precomputed 4D motion field" by Christophe Blondel et al., Physics In Medicine and Biology, vol. 49, no. 11,7, pages 2197-2208 (June 2004) discloses a method for performing a three-dimensional tomographic reconstruction of coronary arteries from cone-beam rotational X-ray angiography acquisitions. Coronary artery motion is precomputed and modeled as a parametric four-dimensional motion field. This parametric four-dimensional motion field is incorporated in the tomographic reconstruction process for reducing motion artifacts in an image of the coronary arteries.

[0006] The article "Retrospective Motion Correction in Digital Substraction Angiography: A Review" by Erik H. W. Meijering et al., IEEE Transactions on Medical Imaging, vol. 18, no. 1, (January 1999) discloses digital subtraction angiography for the visualization of blood vessels in the human body, wherein images acquired at different energy levels are subtracted. The energy-dependent linear X-ray attenuation coefficient of iodine shows a discontinuity at 33 keV, whereas the attenuation coefficients of bone and soft tissue vary only gradually as a function of energy. This implies that the iodine contrast in images obtained using X-rays above this edge is larger than in images obtained with X-rays below this edge. Subtraction results in a reduction of background structures, while the iodine contrast is enhanced.

[0007] While these techniques have proven useful, there remains room for improvement. More particularly, it remains desirable to provide an improved motion compensated reconstruction of an object of interest.

[0008] Aspects of the present application address these matters and others.

[0009] In accordance with one aspect, a computed tomography apparatus includes a motion calculator and a reconstructor. The reconstructor reconstructs energy resolved first radiation projection data to generate first image data indicative of an object under examination at at least first and second motion states. The motion calculator uses the first image data to calculate a motion of the object, and the reconstructor further performs a motion compensated reconstruction using the calculated motion and second radiation projection data to generate second image data indicative of the object. The computed tomography apparatus further comprises an energy pre-processor which uses a pre-processing technique to generate the energy resolved first radiation projection data. The first energy resolved projection data includes projection data which has been pre-processed to selectively identify a substance present in the object. The energy pre-processor comprises a modeling unit for modeling an attenuation by the object as a combination of an attenuation of the substance with a k-edge and a characteristic attenuation spectrum and at least one of a) a photo-electric effect with a characteristic photo-electric attenuation spectrum (P(E)) and a Compton effect with a characteristic Compton attenuation spectrum (C(E)), and b) attenuations of materials of the object.

[0010] According to another aspect of the invention, a tomographic method includes reconstructing energy resolved first projection data to generate first image data indicative of an object at at least first and second motion states, using the first image data to estimate a motion of the object, and reconstructing second projection data to generate second image data indicative of the object. Reconstructing the second projection data includes using the estimated motion to compensate for a motion of the object during acquisition of the second projection data. The tomographic method further includes performing, prior to the step of reconstructing the energy resolved first projection data, an energy pre-processing of projection data acquired during a computed tomography scan of the object. The energy pre-processing includes processing projection data acquired during the scan to obtain projection data indicative of a substance of interest in the

object. An attenuation by the object is modeled by a modeling unit as a combination of an attenuation of the substance with a k-edge and a characteristic attenuation spectrum and at least one of a) a photo-electric effect with a characteristic photo-electric attenuation spectrum (P(E)) and a Compton effect with a characteristic Compton attenuation spectrum (C(E)), and b) attenuations of materials of the object. Preferred embodiments are defined in the dependent claims.

[0011] Still further aspects of the present invention will be appreciated to those of ordinary skill in the art upon reading and understand the following detailed description.

[0012] The invention may take form in various components and arrangements of components, and in various steps and arrangements of steps. The drawings are only for purposes of illustrating the preferred embodiments and are not to be construed as limiting the invention.

FIGURE 1 depicts a computed tomography system.
FIGURE 2 depicts an energy pre-processor.
FIGURE 3 depicts motion vectors indicative of the motion of an object.
FIGURE 4 depicts an imaging method.

[0013] With reference to FIGURE 1, a CT scanner 10 includes a rotating gantry 18 which rotates about the z-axis. The gantry 18 supports a polychromatic x-ray source 12 such as a conventional x-ray tube and an energy resolving x-ray detector 20 which generates x-ray projection data at a plurality of projection angles or views with respect to the examination region 14.

[0014] The detector 20 includes a generally two dimensional array of detector elements 100 which generate outputs indicative of detected radiation falling within a plurality of energy ranges or bins b_i. Energy resolving detectors may be implemented using photon counting detectors, for example as disclosed in Llopart, X., et al., First test measurements of a 64k pixel readout chip working in a single photon counting mode, Nucl. Inst. and Meth. A, 509(1-3): 157-163 (2003); Llopart, X., et al. Medipix2:A 64-k pixel readout chip with 55 μm square elements working in a single photon counting mode, IEEE Trans. Nucl. Sci. 49(5):2279-2283 (2002). Other energy resolving detector implementations using multiple scintillators, direct conversion or other detectors, energy filters, other photon counting detector implementations, or other suitable energy resolving techniques either alone or in combination are also contemplated.

[0015] An object support 16 such as a couch supports a patient or other subject in the examination region 14. The object support 16 is advantageously movable in coordination with a scan so as to provide a circular, helical, saddle, or other desired scan trajectory. A contrast agent injector 6 operatively connected to the controller 28 provides for the injection of an iodinated or other contrast agent, and a biological monitor 8 such as an electrocardiogram (ECG) monitor provides information regarding the cardiac phase or other motion state of the subject. As is conventional in the art, the biological monitor 8 signal can in the case of retrospective gating be used to correlate the projection data with the motion phase or state at which it was acquired. In prospective gating, the biological monitor signal 8 can be used to acquire data at the desired motion state(s) or phase(s).

[0016] An energy pre-processor 24 processes the information from the energy resolving detector 20 to generate projection data indicative of an energy or material of particular interest. In one implementation, and as will be discussed further below, the energy pre-processor 24 processes the detector 20 signals to generate projection data representative of a contrast agent injected using the injector 6 or otherwise present in the subject.

[0017] A reconstructor 22 reconstructs projection data from the energy pre-processor 24 to generate image data. In the case of a retrospectively gated reconstruction, projection data corresponding to one or more desired motion states or phases of the subject or a region of interest thereof is used to reconstruct image data corresponding to the desired phase(s). In one implementation, and as will be discussed further below, the reconstructor 22 operates on projection data which has been processed by the energy pre-processor 26 to generate image data which is indicative largely of the contrast agent or other material of interest at each of a plurality of motion states or phases. A motion calculator 26 uses the reconstructed image data to estimate a motion of the object. The motion information is then used by the reconstructor 22 to carry out a motion compensated reconstruction.

[0018] A general purpose computer serves an operator console 44. The console 44 includes a human readable output device such as a monitor or display and an input device such as a keyboard and mouse. Software resident on the console allows the operator to control the operation of the scanner 10 by establishing desired scan protocols, initiate and terminate scans, view and otherwise manipulate images and other data from the scans, and otherwise interact with the scanner 10, for example through a graphical user interface (GUI).

[0019] As noted above, the energy pre-processor 24 processes the projection data from the detector 20 to provide projection data having a desired spectral characteristic. In one implementation, and with reference to FIGURE 2, the pre-processor 24 employs a k-edge imaging technique to generate projection data indicative of a contrast agent or other substance present in the subject.

[0020] The inputs to the energy pre-processor 24 include energy resolved detector signals d_1, d_2 ... d_i indicative of energy detected in a plurality of energy ranges or bins. In the case of k-edge detection, i is preferably greater than or

equal to three (3). The detection signals d_i exhibit a spectral sensitivity $D_i(E)$ of the i-th energy bin or range b_i. Furthermore, the emission spectrum T(E) of the polychromatic radiation source 12 is generally known.

[0021] A modeling unit 202 models the attenuation by the subject as a combination of the photo-electric effect with characteristic attenuation spectrum P(E), the Compton effect with characteristic attenuation spectrum C(E), and the substance (e.g., a contrast medium) with a k-edge in an energy range of interest and a characteristic attenuation spectrum K(E). The density length product for each of the components, in particular that of the photo-effect component p, the Compton effect component c, and the k-edge component k, enter the modeling of each detection signal d_i according to the relationship:

Equation 1

$$d_i = \int dE \cdot T(E) \cdot D_i(E) \cdot \exp(-p \cdot P(E) - c \cdot C(E) - k \cdot K(E))$$

[0022] Where at least three detection signals d_1, d_2, d_3 are available for at least three energy ranges or bins b_1, b_2, b_3, a system of at least three equations is formed having three unknowns, which can thus be solved with known numerical methods in a calculation unit 204. It is preferred to use a maximum likelihood approach that takes the noise statistics into account. The results, in particular the components p, c, and k, can then be used alone or in combination to reconstruct images of the desired component using conventional reconstruction methods.

[0023] While three energy ranges or bins b_i are generally sufficient to determine the components p, c, and k, improved sensitivity and noise robustness may generally be obtained by improving the energy resolution of the input signal, for example by increasing the number of ranges or bins b_i.

[0024] The above energy processing technique is also disclosed in commonly assigned European Patent Application No. EP05108745.0, filed September 22, 2005 and entitled *CT Imaging System,* which application is expressly incorporated by reference in its entirety herein.

[0025] As noted above, the motion calculator 26 uses reconstructed image data to calculate a motion of the object. An exemplary calculation will be described with reference to FIGURE 3, which is a schematic representation of a reconstructed image space showing the location of two arbitrary points 302, 304.

[0026] The positions of point 302 at the respective measurement times or phases t0, t1, t2 is shown as 302_{t1}, 302_{t1}, 302_{t2}; the position of point 304 is likewise depicted as 304_{t0}, 304_{t1}, 304_{t2}. The motion calculator 26 uses the locations to calculate motion vectors $302_{V1}(x,y,z)$, $302_{V2}(x,y,z)$, $304_{V1}(x,y,z)$, $304_{V2}(x,x,x)$ which describe the motion of the points 302, 304 between the respective measurement times. While FIGURE 3 depicts the motion in two (2) dimensions for ease of illustration, those of ordinary skill in the art will appreciate that, in the case of a three dimensional image volume, the motion vector would ordinarily be a three (3) dimensional vector. Note that the motion values may also be calculated for only one (1) or for three (3) or more points or regions. The motion vectors can also be calculated on other than a point-wise basis, for example by using shape fitting, elastic deformation, or other techniques to estimate a change in shape of the object or an ROI thereof. Additionally, the motion vector field can be determined for the entire volume by a spatial extra-/interpolation of the motion vectors at the different volume positions. The interpolation may be performed according to known techniques, for example using a simple linear interpolation, a thin plate spline interpolation, or the like. The order of the interpolation is typically a function of the number of acquired spatial locations. Similarly, the motion vectors may be calculated for only two (2) or for four (4) or more time periods or phase points.

[0027] Once the motion vector field has been determined for the entire volume or a sub-volume of interest and for a motion state of one cardiac phase to the motion state of another cardiac phase, the reconstructor 22 uses the motion vectors to perform a motion compensated reconstruction. In one such technique, the motion vectors are used directly in the motion compensation by modifying a voxel position in the reconstruction volume according to the cardiac phase of the projection to be backprojected. In other words, the motion compensated reconstruction should be performed for all projections within the temporal window around the cardiac phase from which the data are taken for a conventional gated CT reconstruction and based on that a determination of the motion vector field. The motion compensation may also be performed following at least one of a temporal or spatial interpolation of the motion vectors.

[0028] The calculation of the motion vectors (using segmented data) and a corresponding motion compensated reconstruction is also discussed in commonly assigned European Patent Application No. EP05111216.7, filed November 24, 2005 and entitled *Motion compensated CT reconstruction of high contrast objects,* which application is expressly incorporated by reference in its entirety herein.

[0029] With reference to FIGURE 4, operation will now be described in relation to an exemplary contrast enhanced cardiac scan.

[0030] Scan data is acquired at 402, for example using a conventional low pitch helical, circular, saddle, or other desired scan trajectory. In the exemplary case of a contrast enhanced cardiac examination, a contrast agent is introduced

into the anatomy of the subject in coordination with the scan using known techniques. Signals from the ECG 8 are also acquired in conjunction with the projection data.

[0031] An energy pre-processing is performed at 404. In the exemplary contrast enhanced cardiac scan, a k-edge processing technique is used to generate projection data indicative of contrast agent present in an ROI which includes at least a portion of the heart.

[0032] The pre-processed projection signals are reconstructed at step 406 to generate image data at each of a plurality of cardiac phases. It will be appreciated that, in the present k-edge imaging example, the reconstructed image data is largely indicative of the concentration of contrast agent in the region of the heart. As will also be appreciated, the contrast agent can ordinarily be expected to have a relatively greater contrast relative to the surrounding tissues as compared to images generated from a conventional polyenergetic CT data set.

[0033] The motion of the desired points or regions of the heart at one or more phase points is calculated at step 408. Note that, prior to performing the motion calculation, segmentation, clustering, or other suitable image processing operations may optionally be performed to further identify regions containing contrast agent.

[0034] At step 410, information from the motion calculations are used to perform a motion compensated reconstruction at one or more desired cardiac phases. In this regard, it should be noted that the motion compensated reconstruction may be performed on the k-edge data, photoelectric spectrum data, the Compton spectrum data (or a combination thereof), data processed to approximate a conventional polyenergetic data set, or other desired spectral data, whether pre-processed or otherwise.

[0035] At step 412, the reconstructed image data is displayed in human readable form, for example on a monitor associated with the operator console 44.

[0036] Variations are contemplated. For example, the spectral information may be obtained other than through the use of energy resolving detectors. Thus, for example, x-ray source(s) which produce radiation having the desired spectral characteristics and/or time varying or other filters which selectively harden or otherwise alter the spectral characteristics of the radiation may also be used.

[0037] Other pre-processing techniques which identify a substance of interest or otherwise provide a desired material separation may also be implemented. For example, basis material combinations other than photo/Compton, including but not limited to bone/soft tissue and calcium/water may also be provided. Depending on the technique, data indicative of two (2) energy ranges or bins may be used, for example where it is desirable to solve for the photoelectric and Compton components of the acquired projection data, or where it is desired to interpolate the energy resolved data. The energy pre-processor 24 may also be omitted, in which case the reconstructor 22 may operate directly on the energy resolved projection data. An energy-based post processor which operates on the image data may also be used to identify a substance of interest or otherwise provide a desired material separation.

[0038] While the above description has focused on cardiac imaging, the described techniques may also be used in connection with regions of interest other than the heart, or to compensate for respiratory or other motion.

[0039] The energy pre-processor 24, reconstructor 22, and motion calculator 26 may be implemented by way of computer readable instructions which, when executed by a computer processor(s), cause the processor(s) to carry out the described techniques. In such a case, the instructions are stored in a computer readable storage medium associated with or otherwise accessible to the relevant computer. Note also that the described techniques need not be performed concurrently with the data acquisition. They may also be performed using a computer (or computers) which are associated with the scanner 10; they may also be located remotely from the scanner 10 and access the relevant data over a suitable communications network such as a HIS/RIS system, PACS system, the internet, or the like.

[0040] It should also be noted that the reconstruction has been discussed in terms of a single reconstructor 22. The reconstructor 22 may include multiple reconstruction units or algorithms, for example a first reconstruction unit or algorithm which carries out a reconstruction used to calculate the object motion and a second unit or algorithm which carries out the motion compensated reconstruction.

[0041] The described techniques are also applicable to imaging modalities other than x-ray CT. Thus, for example, the techniques may be applied in coherent scatter CT, positron emission tomography (PET), single photon emission computed tomography (SPECT), or other applications in which motion compensation is required.

[0042] The invention has been described with reference to the preferred embodiments. Modifications and alterations may occur to others upon reading and understanding the preceding detailed description. It is intended that the invention be construed as including all such modifications and alterations insofar as they come within the scope of the appended claims or the equivalents thereof.

Claims

1. A computed tomography apparatus comprising:

a motion calculator (26);
a reconstructor (22) which reconstructs energy resolved first radiation projection data to generate first image data indicative of an object under examination at at least first and second motion states, wherein the motion calculator uses the first image data to calculate a motion of the object, and wherein the reconstructor further performs a motion compensated reconstruction using the calculated motion and second radiation projection data to generate second image data indicative of the object;
an energy pre-processor (24) which uses a pre-processing technique to generate the energy resolved first radiation projection data, wherein the first energy resolved projection data includes projection data which has been pre-processed to selectively identify a substance present in the object, wherein the energy pre-processor comprises a modeling unit (202) for modelling an attenuation by the object as a combination of an attenuation of the substance with a k-edge and a characteristic attenuation spectrum (K(E)) and at least one of a) a photo-electric effect with a characteristic photo-electric attenuation spectrum (P(E)) and a Compton effect with a characteristic Compton attenuation spectrum (C(E)), and b) attenuations of materials of the object.

2. The apparatus of claim 1 wherein the energy pre-processor receives input signals indicative of radiation detected in at least three energy bins (bi).

3. The apparatus of claim 1 wherein the second radiation projection data includes at least one of Compton effect data and photo-effect data.

4. The apparatus of claim 1 wherein the object includes a beating heart, the first and second motion states include first and second cardiac phases, and the first image data includes first data representative of the first cardiac phase and second data representative of the second cardiac phase.

5. The apparatus of claim 1 wherein the motion calculator calculates a plurality of three dimensional motion vectors.

6. The apparatus of claim 1 wherein the motion calculator performs at least one of a spatial and a temporal interpolation of the first image data.

7. The apparatus of claim 1, wherein the apparatus further comprises:

an object support (16) adapted to support a subject in an examination region (14);
an x-ray source (12) which rotates about the examination region; and
an x-ray detector (20) which acquires energy resolved projection data, wherein the projection data includes first data indicative of detected x-rays having a first energy and second data indicative of detected x-rays having a second energy.

8. A tomographic method comprising:

reconstructing energy resolved first projection data to generate first image data indicative of an object at at least first and second motion states;
using the first image data to estimate a motion of the object;
reconstructing second projection data to generate second image data indicative of the object, wherein reconstructing the second projection data includes using the estimated motion to compensate for a motion of the object during acquisition of the second projection data;
performing, prior to the step of reconstructing the energy resolved first projection data, an energy pre-processing of projection data acquired during a computed tomography scan of the object, wherein the energy pre-processing includes processing projection data acquired during the scan to obtain projection data indicative of a substance of interest in the object, wherein an attenuation by the object is modelled by a modeling unit (202) as a combination of an attenuation of the substance with a k-edge and a characteristic attenuation spectrum (K(E)) and at least one of a) a photo-electric effect with a characteristic photo-electric attenuation spectrum (P(E)) and a Compton effect with a characteristic Compton attenuation spectrum (C(E)), and b) attenuations of materials of the object.

9. The method of claim 8 wherein using the first image data includes estimating a motion of a region of the object.

10. The method of claim 8 wherein the first and second projection data are acquired substantially temporally simultaneously.

Patentansprüche

1. Computertomographiegerät, das Folgendes umfasst:

einen Bewegungsberechnungseinheit (26);
eine Rekonstruktionseinheit (22), die energieaufgelöste erste Strahlungsprojektionsdaten rekonstruiert, um erste Bilddaten zu erzeugen, die ein untersuchtes Objekt bei mindestens ersten und zweiten Bewegungszuständen darstellen, wobei die Bewegungsberechnungseinheit die ersten Bilddaten verwendet, um eine Bewegung des Objekts zu berechnen, und wobei die Rekonstruktionseinheit weiterhin eine bewegungskompensierte Rekonstruktion unter Verwendung der berechneten Bewegung und zweiter Strahlungsprojektionsdaten durchführt, um zweite Bilddaten zu erzeugen, die das Objekt darstellen;
einen Energievorprozessor (24), der eine Vorverarbeitungstechnik anwendet, um die energieaufgelösten ersten Strahlungsprojektionsdaten zu erzeugen, wobei die ersten energieaufgelösten Projektionsdaten Projektionsdaten umfassen, die vorverarbeitet wurden, um selektiv eine in dem Objekt vorhandene Substanz zu identifizieren, wobei der Energievorprozessor eine Modelliereinheit (202) zum Modellieren einer Abschwächung durch das Objekt als eine Kombination einer Abschwächung der Substanz mit einer k-Kante und einem charakteristischen Abschwächungsspektrum (K(E)) und mindestens entweder a) einem photoelektrischen Effekt mit einem charakteristischen photoelektrischen Abschwächungsspektrum (P(E)) und einem Compton-Effekt mit einem charakteristischen Compton-Abschwächungsspektrum (C(E)) oder b) Abschwächungen von Materialien des Objekts umfasst.

2. Gerät nach Anspruch 1, wobei der Energievorprozessor Eingangssignale empfängt, die die in mindestens drei Energieklassen (bi) detektierte Strahlung angeben.

3. Gerät nach Anspruch 1, wobei die zweiten Strahlungsprojektionsdaten mindestens entweder Compton-Effekt-Daten oder Photoeffekt-Daten enthalten.

4. Gerät nach Anspruch 1, wobei das Objekt ein schlagendes Herz umfasst, wobei die ersten und zweiten Bewegungszustände erste und zweite Herzphasen umfassen, und wobei die ersten Bilddaten erste Daten umfassen, welche die erste Herzphase darstellen, und zweite Daten, welche die zweite Herzphase darstellen.

5. Verfahren nach Anspruch 1, wobei die Bewegungsberechnungseinheit eine Vielzahl von dreidimensionalen Bewegungsvektoren berechnet.

6. Gerät nach Anspruch 1, wobei die Bewegungsberechnungseinheit mindestens entweder eine räumliche oder eine zeitliche Interpolation der ersten Bilddaten durchführt.

7. Gerät nach Anspruch 1, wobei das Gerät weiterhin Folgendes umfasst:

eine Objektaufnahme (16) zum Halten eines Objekts in einer Untersuchungsregion (14);
eine Röntgenquelle (12), die sich um die Untersuchungsregion dreht; und
einen Röntgendetektor (20), der energieaufgelöste Projektionsdaten erfasst, wobei die Projektionsdaten erste Daten für detektierte Röntgenstrahlen mit einer ersten Energie und zwei Daten für detektierte Röntgenstrahlen mit einer zweiten Energie beinhalten.

8. Tomographieverfahren, das Folgendes umfasst:

Rekonstruieren von energieaufgelösten ersten Strahlungsprojektionsdaten, um erste Bilddaten zu erzeugen, die ein untersuchtes Objekt bei mindestens ersten und zweiten Bewegungszuständen darstellen;
Verwenden der ersten Bilddaten, um eine Bewegung des Objekts zu schätzen;
Rekonstruieren zweiter Projektionsdaten, um zweite Bilddaten zu erzeugen, die das Objekt darstellen, wobei das Rekonstruieren der zweiten Projektionsdaten die Verwendung der geschätzten Bewegung zum Kompensieren einer Bewegung des Objekts während der Erfassung der zweiten Projektionsdaten umfasst;
vor dem Schritt des Rekonstruierens der energieaufgelösten ersten Projektionsdaten Durchführen einer Energievorverarbeitung der während eines Computertomographie-Scans des Objekt erfassten Projektionsdaten, wobei die Energievorverarbeitung die Verarbeitung von während des Scans erfassten Projektionsdaten umfasst, um Projektionsdaten zu erhalten, die auf eine interessierende Substanz im Objekt hinweisen, wobei eine Abschwächung durch das Objekt von einer Modelliereinheit (202) modelliert wird als eine Kombination einer

Abschwächung der Substanz mit einer k-Kante und einem charakteristischen Abschwächungsspektrum (K(E)) und mindestens entweder a) einem photoelektrischen Effekt mit einem charakteristischen photoelektrischen Abschwächungsspektrum (P(E)) und einem Compton-Effekt mit einem charakteristischen Compton-Abschwächungsspektrum (C(E)) oder b) Abschwächungen von Materialien des Objekts.

9. Verfahren nach Anspruch 8, wobei das Verwenden der ersten Bilddaten das Schätzen einer Bewegung einer Region des Objekts umfasst.

10. Verfahren nach Anspruch 8, wobei die ersten und zweiten Projektionsdaten im Wesentlichen zeitlich simultan erfasst werden.

Revendications

1. Appareil de tomodensitométrie, comprenant :

un calculateur de mouvement (26) ;
un reconstructeur (22) qui reconstruit des premières données de projection de rayonnement à résolution énergétique afin de générer des premières données d'image indicatives d'un objet examiné dans au moins un premier et un deuxième état de mouvement, ledit calculateur de mouvement utilisant les premières données d'image pour calculer un mouvement de l'objet et ledit reconstructeur effectuant en plus une reconstruction de mouvement compensée en utilisant le mouvement calculé et des deuxièmes données de projection de rayonnement afin de générer des deuxièmes données d'image indicatives de l'objet ;
un préprocesseur d'énergie (24) qui utilise une technique de prétraitement pour générer les premières données de projection de rayonnement à résolution énergétique, lesdites premières données de projection à résolution énergétique comprenant des données de projection qui ont été prétraitées afin d'identifier sélectivement une substance présente dans l'objet, ledit préprocesseur d'énergie comprenant un module de modélisation (202) servant à modéliser une atténuation par l'objet sous la forme d'une combinaison d'une atténuation de la substance ayant un bord k et un spectre d'atténuation caractéristique (K(E)) et présentant au moins un effet parmi a) un effet photoélectrique avec un spectre d'atténuation photoélectrique caractéristique (P(E)) et un effet Compton avec un spectre d'atténuation Compton caractéristique (C(E)), et b) des atténuations par des matières de l'objet.

2. Appareil selon la revendication 1, dans lequel le préprocesseur d'énergie reçoit des signaux d'entrée indicatifs du rayonnement détecté dans au moins trois intervalles d'énergie (bi).

3. Appareil selon la revendication 1, dans lequel les deuxièmes données de projection de rayonnement comprennent l'une au moins parmi des données d'effet Compton et des données d'effet photoélectrique.

4. Appareil selon la revendication 1, dans lequel l'objet comprend un coeur qui bat, les premier et deuxième états de mouvement comprennent des premières et deuxièmes phases cardiaques, et les premières données d'image comprennent des premières données représentatives de la première phase cardiaque et des deuxièmes données représentatives de la deuxième phase cardiaque.

5. Appareil selon la revendication 1, dans lequel le calculateur de mouvement calcule une pluralité de vecteurs de mouvement en trois dimensions.

6. Appareil selon la revendication 1, dans lequel le calculateur de mouvement effectue l'une au moins parmi une interpolation spatiale et une interpolation temporelle des premières données d'image.

7. Appareil selon la revendication 1, dans lequel l'appareil comprend en plus :

un support d'objet (16) adapté pour supporter un sujet dans une région à examiner (14) ;
une source de rayons X (12) qui tourne autour de la région à examiner ; et
un détecteur (20) de rayons X qui acquiert des données de projection à résolution énergétique, lesdites données de projection comprenant des premières données indicatives de rayons X détectés ayant une première énergie et des deuxièmes données indicatives de rayons X détectés ayant une deuxième énergie.

8. Procédé de tomodensitométrie, comprenant les étapes consistant à :

reconstruire des premières données de projection à résolution énergétique afin de générer des premières données d'image indicatives d'un objet dans au moins un premier et un deuxième état de mouvement ;
utiliser les premières données d'image pour estimer un mouvement de l'objet ;
reconstruire des deuxièmes données de projection afin de générer des deuxièmes données d'image indicatives de l'objet, ladite reconstruction des deuxièmes données de projection comprenant l'utilisation du mouvement estimé pour compenser un mouvement de l'objet pendant l'acquisition des deuxièmes données de projection ;
effectuer avant l'étape de reconstruction des premières données de projection à résolution énergétique un prétraitement de l'énergie des données de projection acquises pendant une exploration tomodensitométrique de l'objet, ledit prétraitement d'énergie comprenant le traitement de données de projection acquises pendant l'exploration afin d'obtenir des données de projection indicatives d'une substance d'intérêt présente dans l'objet, une atténuation par l'objet étant modélisée par un module de modélisation (202) sous la forme d'une combinaison d'une atténuation de la substance ayant un bord k et un spectre d'atténuation caractéristique (K(E)) et d'au moins un effet parmi a) un effet photoélectrique avec un spectre d'atténuation photoélectrique caractéristique (P(E)) et un effet Compton avec un spectre d'atténuation Compton caractéristique (C(E)), et b) des atténuations de matières de l'objet.

9. Procédé selon la revendication 8, dans lequel l'utilisation des premières données d'image comprend l'estimation d'un mouvement d'une région de l'objet.

10. Procédé selon la revendication 8, dans lequel les premières et deuxièmes données de projection sont acquises de manière pratiquement simultanée dans le temps.

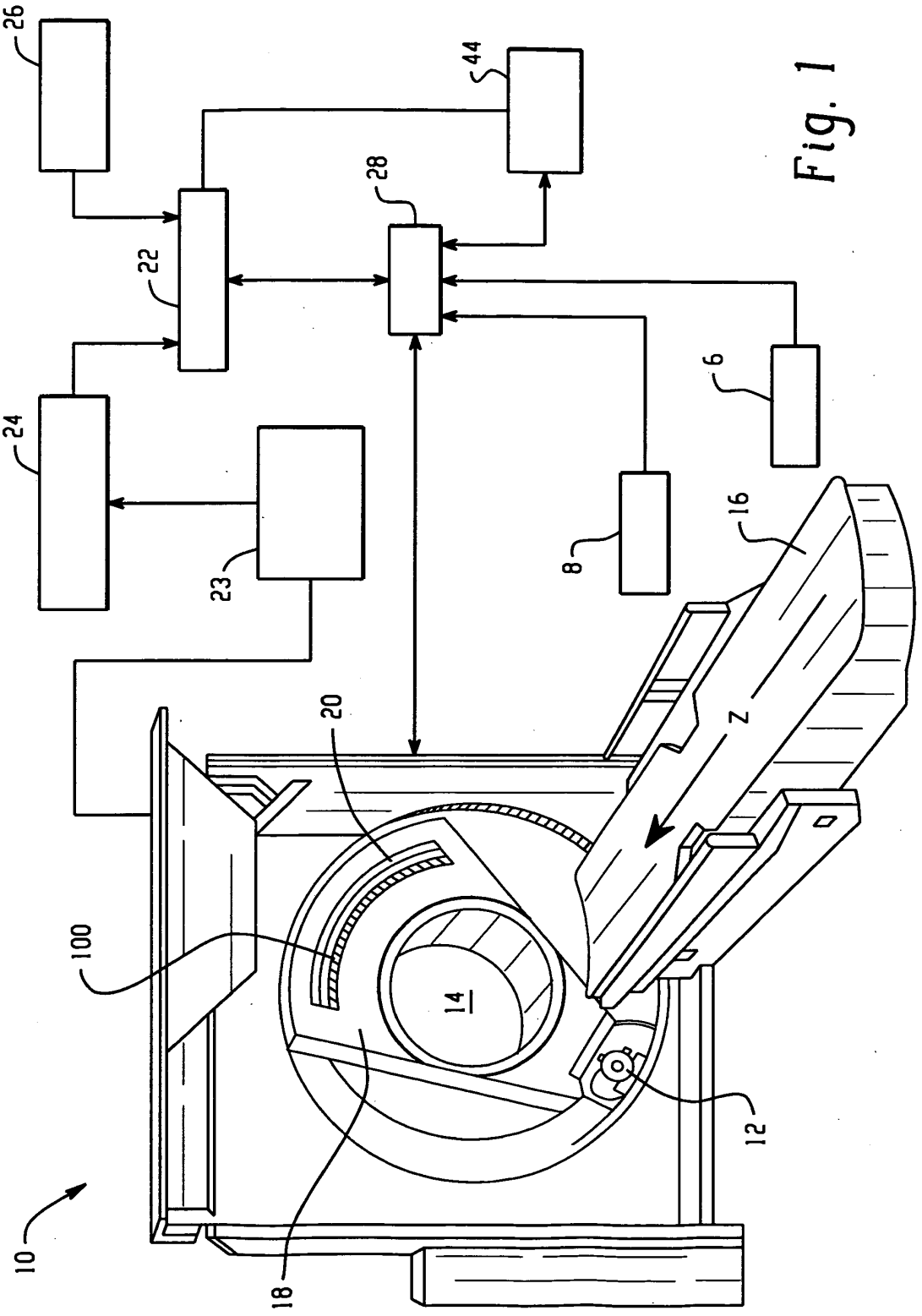


Fig. 1

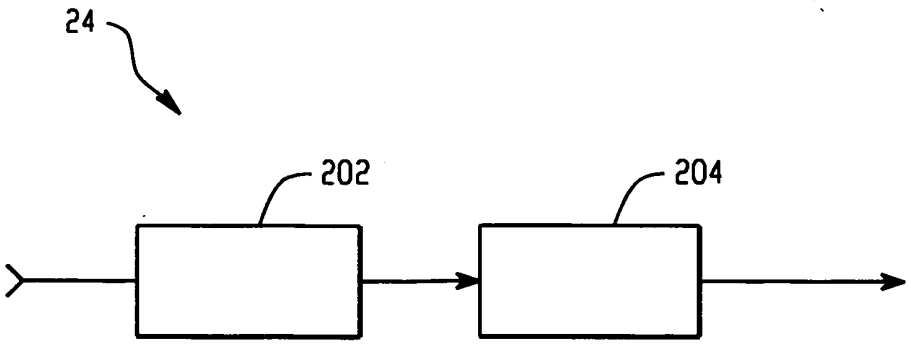

24
202
204

Fig. 2

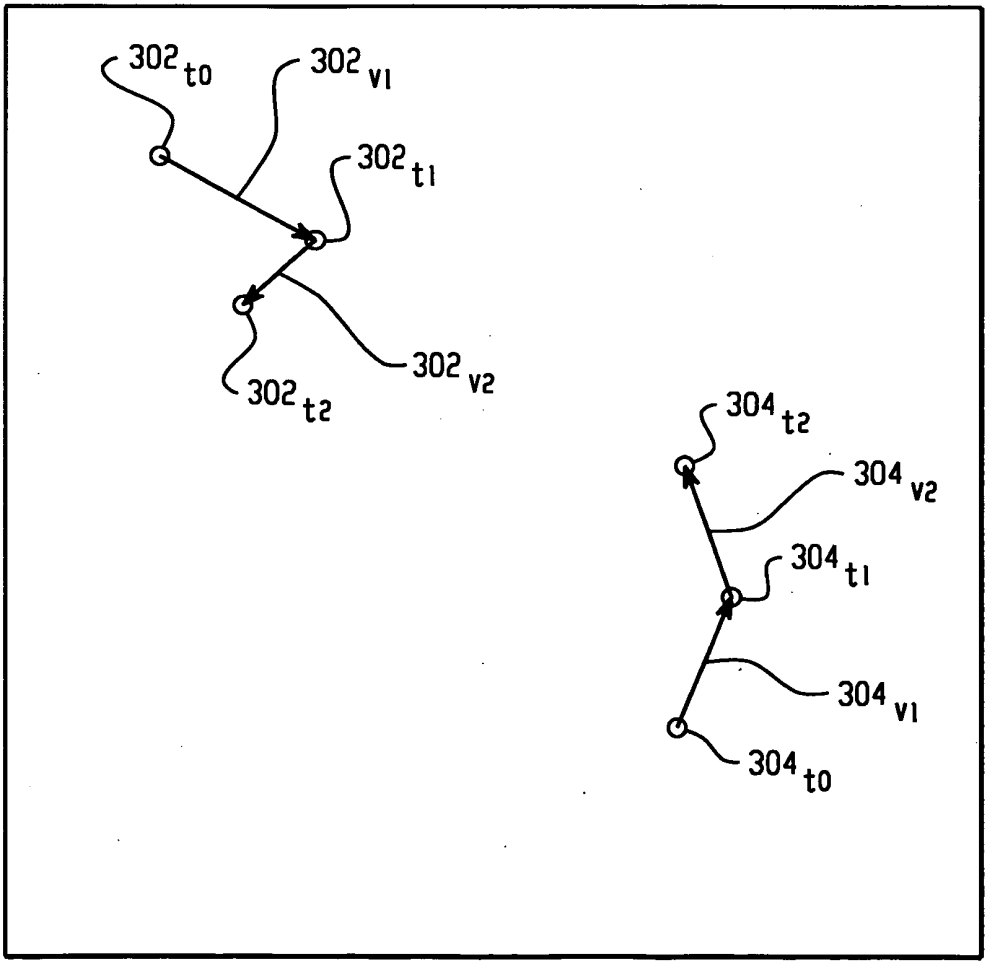

302 t0
302 v1
302 t1
302 v2
302 t2
304 t2
304 v2
304 t1
304 v1
304 t0

Fig. 3

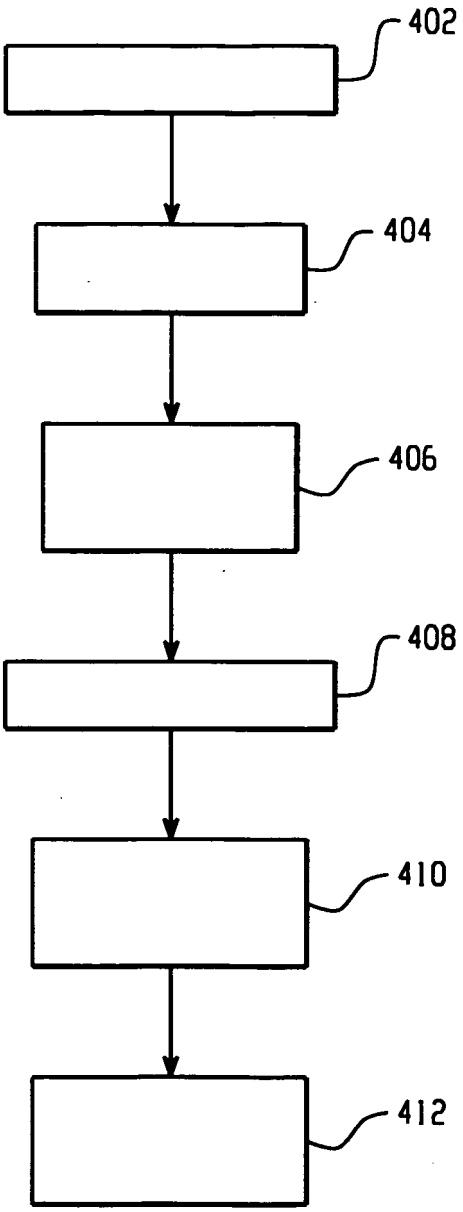


Fig. 4

REFERENCES CITED IN THE DESCRIPTION

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